Design and Performance of Water Flow Velocity Calibration Facility

Heming Hu[1], Yuan Liu[1], Zhigang Wang[2], Zeyu Guo[1], Yunlong Zhu[1]

1. National Institute of Metrology, Beijing 100029, China;
2. China Institute of Water Resources and Hydropower Research, Beijing 100038, China;
E-mail: huhm@nim.ac.cn

Abstract: Current meters are used for flow velocity measurement in river and ocean. Accurate measurements need accurate calibrations. There are more than ten tow tank facility in China providing water velocity calibration, and all of them are ~100 m long concrete tank with no clear uncertainty budget, especially there is not a thorough understanding of the water movements in the tow tank. We have built a small tow tank which is 8 m long, 1.2 m wide and 1.2 m high with a cart running speed of 0.01m/s~1m/s. It was made of transparent glass and was possible to use optical instruments to investigate the background flow filed that might compromise calibration results. In order to test the performance of flow velocity calibration facility, Micro ADV produced by Sontek was employed to make a test, and the results showed that the calibrated results for ADV using flow velocity calibration facility proposed in this article agreed well with the manufacture's declaration for accuracy and USGS's conclusions. In addition, SNR (signal-noise ratio) of MicroADV was also analysed and related to the concentration of particles in water body. The performances verified that the flow velocity calibration facility was effective and could be used to conduct further analysis of current meters.

Key words: flow velocity, flow velocity calibration facility, open channel, MicroADV

1 Introduction

Flow velocity is an important hydraulic index in various flows. How to determine it have been a focus for a long time. Various of current meters have been developed to determine the key velocities, for example electromagnetic current meters, ultrasonic current meters, ADVs, and widely used rotating current meters (GB/T11826, 2002, Yao 2012, Voulgaris & Trowbridge 1998, Hurther & Lemmin, 2001, Parsheh et al. 2010, Jiang et al. 2010, Xiao et al. 2002). However, subject to the measuring mechanism, nearly all types of current meters couldn't perform perfectly with no errors. For example, the rotating current meters perform badly in the cases with ultra-low velocities where the effective signals are seriously overwhelmed by errors. ADVs will give good flow velocity measurements only if enough particles exist in the measured flow.

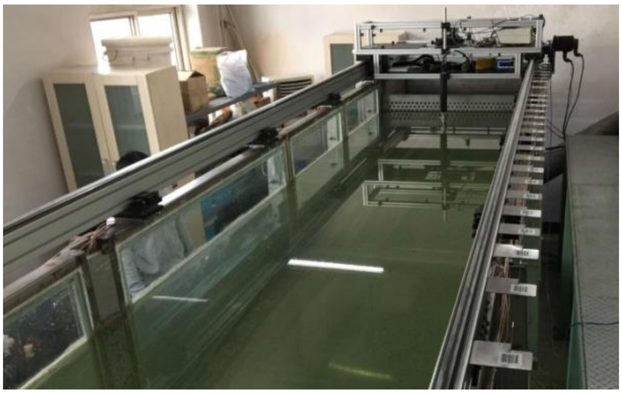
Therefore the current meters should be pre-calibrated before used. Traditionally, the calibration facility for current meters are a specially constructed long flume (mostly>100m) in earth. A cart is mounted over the flume and its speed can be set according to requirements. When needed to be calibrated, the current meters can be fixed on the cart and move together with the cart. Comparing the cart's speeds and the current meter's indications can clearly show the performance of the current meter, and the adjusting curve can also be provided. However, the traditional calibration facility can't give elaborated illustrations of the interaction of current meter and the tested flows. And the influences of water quality, abundance of particles, background velocities are also not easy to be obtained. Thus in this paper, a new flow velocity calibration facility was designed and constructed. And its performance would be testified by Micro ADV, a kind of widely used ADV current meters produced by Sontek (Sontek/YSI, 2001).

As is known, the noise is existing during the whole measuring procedure, and its influences couldn't be ignored. Many researchers have done lots of researches (He 2013, Marc & Beat 2012, Yan et al. 2017), however, how to reduce the disturbance of noise to achieve a higher accuracy has not reached an agreement. In addition, USGS organized a comparison tests of ADV in global in 2013. The tested revealed that background velocity, rod shape and size, vibration, concentration of tracer particles would probably affect the calibration results. And the accuracy should be re-verified when the flow velocity was low (0.01~0.1m/s)

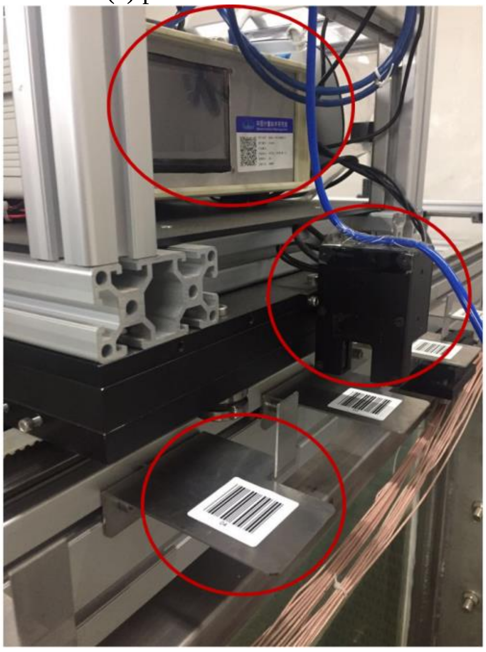
2 Design of water flow velocity calibration facility

2.1 *Composition and Function*

The main part of the flow velocity calibration facility was the flume, which was shown in Fig.1. It was 8m×1.2m×1.2m (length ×width ×depth). The frame of the flume was made of stainless steel. The glass was arranged inside the frame in order for a convenience for visual observation. As the velocity of cart could be easily determined, thus the standard flow velocity was simulated by a moving cart velocity relative to the still water. The rails, on which the cart runs, were mounted on the top of both sidewalls. The designed cart velocities were 0.01m/s~1m/s. When conducting calibration, the current meter should be fixed to the cart. The current meter holder was made to be a 1m-long cylindrical iron pole with the diameter being 0.02m. The cylindrical shape could well decrease the disturbances produced by itself. In addition, the current meter holder was made with fillets, which was also beneficial to reduce the self-influence.



(a) photos of the tow tank



(b) cart speed measurement system
Fig.1 Flume in flow velocity calibration facility

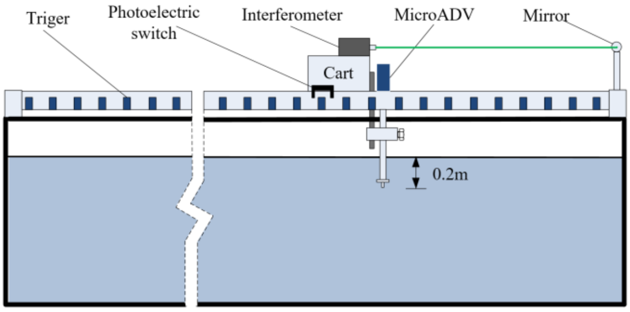


Fig.2 Sketch of cart speed system

2.2 *Cart Speed*

Reliability of flow velocity calibration facility depends on the accuracy of cart speeds. In this flow velocity calibration facility, two sets of cart speed measuring devices were mounted, and one device was Laser Interferometer and the other was Photoelectric Trigger, which were shown in Fig.2. In both devices, the measurements of distance and time were the key. The Laser Interferometer occupied a linear resolution of 0.01μm when measuring the displacements of the cart. The time measurement was conducted by a timer/counter developed by National Institute of Metrology of China. And the relative errors of timing was within 0.01%. The Photoelectric Trigger also referred to the determination of interval of neighboring trigger elements and responding time, and the tested results were shown in Fig.3.

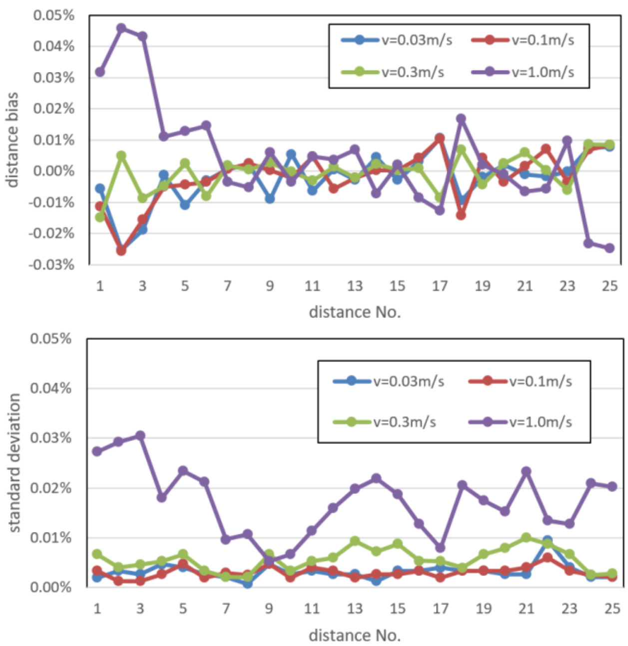


Fig.3 Interval calibration of baffles at different speeds

In this flow velocity calibration facility, photo-electronic components were used. They need different responding times when triggered at different cart speeds. And the responding times increased with increasing cart speeds. In all tested cases, the responding time was restricted within 10μs. If the cart velocity was slow, the responding time could minimized to being within 4μs. Subjected to the responding time, the intervals between neighboring triggers also varied depending on the cart speeds. In the 4 tested cases, the calibrated result at the case when the cart speed was 1.0m/s was more largely deviated from the true value.

Table 1 showed the measuring stability of two cart speed measuring ways. When Laser Interferometer was employed, the relative standard errors decreased with the increasing cart speed. The reason is that the sampled data tended to be less when the cart speed increased at the same sample frequency. If the sample frequency was adjusted, the measuring stability would be changed, namely measuring stability would get worse with increasing sample frequency. When Photoelectric Trigger was used, the quantity of the sampled data would be the same as the quantity of the trigger components was a constant. However, due to the influence of the responding time, the measuring stability of Photoelectric Trigger also performed worse with the increasing cart speed. As for the sample frequency, Chinese national standard makes a recommendation. When the cart speed is slower than 0.2m/s, the speed measuring unit is recommended as 10s, or the speed measuring unit should take the value of 1s.

Table 1 Speed stability of two speed measuring methods

Velocity measuring way	Nominal cart speed (m s^{-1})	Actually cart speed (m s^{-1})	Relative standard deviation (%)
Cart speed measuring by Laser Interferometer	0.03	0.03008	1.33
	0.10	0.10016	0.46
	0.30	0.30012	0.29
	1.00	1.00078	0.63
Cart speed measuring by Photoelectric Trigger	0.03	0.03008	0.06
	0.10	0.10015	0.06
	0.30	0.2999	0.20
	1.00	1.00049	0.66

2.3 *Background velocity*

Background velocity could undoubtedly influence the cart speed as well as the flow velocity measuring. Commonly, it is advisable to conduct physical model tests with large time intervals when no disturbances are introduced. In this section, two typical cases were chosen to reflect the influences of background velocity.

Where the cart speed was 0.3m/s, it was observed that during the towing process, the velocity component of Y direction (X is the traveling direction and Y is the vertical direction of X) fluctuated between -0.01m/s~0.03s/s, and the water body tended to be stable after the waiting time of nearly 2min. It could be seen that the velocity deviation caused by the background velocity couldn't be ignored in the precise measurements.

3 Performance of flow velocity calibration facility

In this section, SonTek MicroADV was employed to make a calibration test. The accuracy of Micro ADV is declared as ±1% and greater than 2.5mm/s.

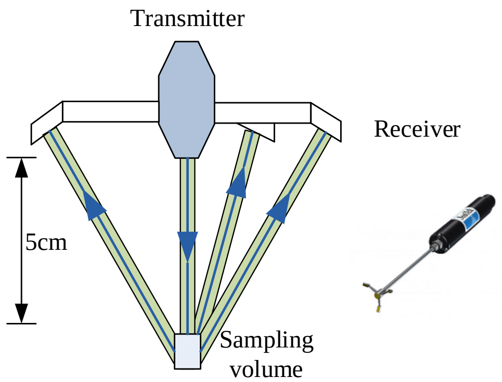


Fig.4 Sontek 16M MicroADV

In this section, 6 typical cart speeds, namely 0.01m/s, 0.03m/s, 0.05m/s, 0.1m/s, 0.3m/s and 1.0m/s, were chosen, and the tested results were shown in Fig.4. Clearly, the measuring error almost exceeded 10% when the cart speed was 0.01m/s while the measuring error was within 1% when the cart speed increased to over 0.1m/s, which agreed well with the manufacture's accuracy declaration.

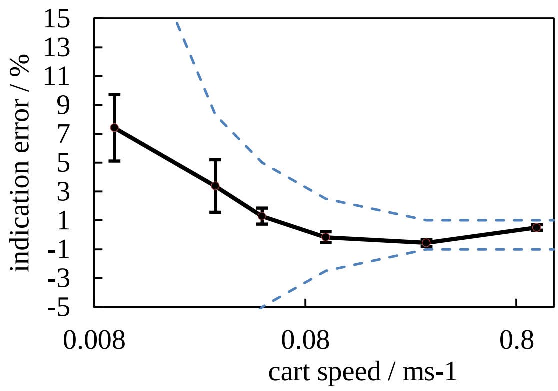
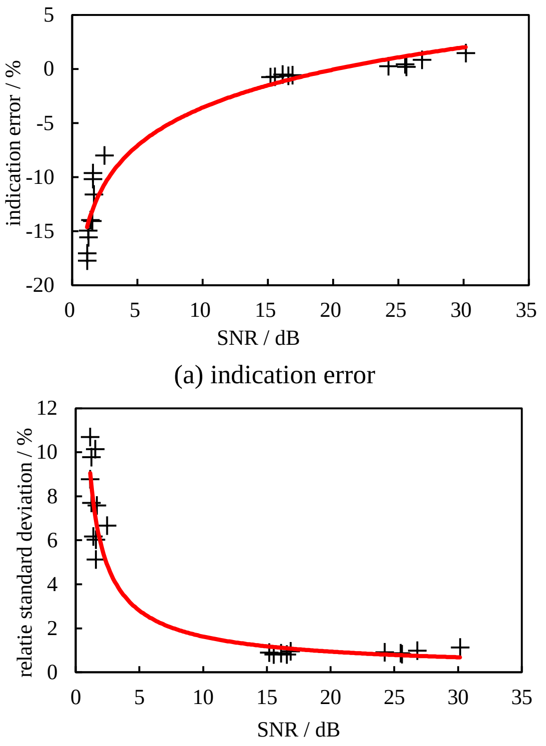


Fig.5 Performance of flow velocity calibrated facility

In addition, USGS have conducted similar experiments. The calibrated current meter chosen was ADV produced by OTT in Germany. The tested results showed that the measuring error was as large as 6% when the cart speed was 0.05m/s. However, when the cart speed increased to 0.4m/s, the measuring error was decreased to within ±1%. In a word, the measuring results of this paper also agreed well with USGS.

From the analysis and comparisons above, it could be concluded that the flow velocity calibrating facility was effective. Besides, this facility can also help us make further analysis of the current meter. As was known, the signal strengths were closely related with the concentration of particles in water body. If the water body was too clean, the strength of the effective signal might be at the same with or lower than the noise level, inducing velocity measuring unsuccessfully. Herein, the signal strengths would be analyzed further, and the results were shown in Fig.7 and Fig.8.



(a) indication error

(b) standard deviation

Fig.6 performance of MicroADV under different SNR

Clearly, as the signal strength increased, the relative standard deviations decreased in an exponential form while the velocity indication errors increased in a logarithmic form. When SNR of Micro ADV was smaller than 5dB, the relative standard deviation of velocity would exceeded 10% and the velocity indication errors would be smaller than -15%. When SNR increased to above than 15dB through increasing the concentration of particles, the velocity measurement would be much more stable, and the relative standard deviation decreased to be within 1%. The velocity indication errors would also be smaller than 2%. After investigation, it was found that the settlement of particles was the main reason to influence the velocity measurement quality. Through observation in still water, the settling velocity of particles were in the range of 0.15cm/s~0.30cm/s. When the particles continued settling till SNR were smaller than 5dB, ADV would fail in velocity measuring. However, the signal strength would not be linear with the concentration of particles. In fact, as the concentration of particles continued increasing, the signal strength would be first increased and then reversed to decrease. The concentration was 0.3% ~ 0.5% when the signal strength got reversed.

4 Conclusions and future work

Current meters are used for flow velocity measurement in river and ocean. Accurate measurements need accurate calibrations. In this paper, a flow velocity calibration facility was established. In this facility, the flow velocity measuring was instead of cart traveling speed's measuring. Laser Interferometer and Photoelectric Trigger were employed to conduct the measurement of distances while a self-designed timer/counter was employed to conduct time determination. And then the cart's velocity could be easily obtained.

In order to test the performance of flow velocity calibration facility, Micro ADV was employed to make a test, and the results showed that the calibrated results for ADV using this facility agreed well with the manufacture's declaration for accuracy. In addition, USGS also made similar conclusions. The performances showed that the flow velocity calibration facility was effective. Besides, the flow velocity calibration facility could also be used to conduct further analysis about the relationship between SNR and the concentration. The results showed that SNR being larger than 15dB could make stable velocity measurement. However, SNR was not linear related with the concentration of particles, and too large concentrations might decrease the effective signal strength.

In the future, we are planning to add a dynamic calibration system to extend its maximum velocity. It will use a pump and a nozzle (outlet diameter is 200mm) to generate a submerged jet with a top-hat velocity profile as testing region. We are planning to test small current meter using LDV as reference from 0.3 m/s to 3 m/s.

Acknowledgments

This paper is currently supported by The National Key R&D Program of China (project/subject SN. 2017YFC 0405705).

References

[1] GB/T11826-2002, Rotating Current Meter[S]. (in Chinese)

[2] HE Qifeng, Research on the Applicability of Acoustic Doppler Velocimeter[D]. Beijing：Tsinghua University,2013. (in Chinese)

[3] Hurther D, Lemmin U. A Correction Method for Turbulence Measurements with a 3D Acoustic Doppler Velocity Profiler[J]. Journal of Atmospheric & Oceanic Technology, 2001,

18(3):446-458.

[4] JIANG Songyan, GAO Wei, LUO Gong. Analysis on Calibration of Acoustic Doppler Current Meter [J].Water Resources Information, 2010.4: 54-56. (in Chinese)

[5] Marc de Huu ，Beat Wuthrich. Gravity wave effects on the calibration uncertainty of hydrometric current meters[C]. IGHEM, Trondheim, Norway 2012.

[6] Parsheh M, Sotiropoulos F, Portéagel F. Estimation of Power Spectra of Acoustic-Doppler Velocimetry Data Contaminated with Intermittent Spikes[J]. Journal of Hydraulic Engineering, 2010, 136(6):368-378.

[7] SonTek/YSI, Inc. Acoustic Doppler Velocimeter Principles of Operation[Z]. 2001

[8] Voulgaris G, Trowbridge J H. Evaluation of the Acoustic Doppler Velocimeter (ADV) for Turbulence Measurements*[J]. Journal of Atmospheric & Oceanic Technology, 1998, 15(15):272-289.

[9] YAN Song, WU Hao, SUN Dapeng,et al. Application of Acoustic Doppler Velocimetry in Flume Flow Experiment [J]. Research and Exploration in Laboratory 2017.36(5): 9-13. (in Chinese)

[10] YAO Yongxi.Calibration Method Comparison of Rotating Element Current Meters in China and Other Countries[J].Hydrology, 2012(3):1-5. (in Chinese)